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TECHNOLOGICAL ASPECTS OF THE SUITABILITY OF ROCKS FROM DIFFERENT DEPOSITS FOR THE PRODUCTION OF CONTINUOUS BASALT FIBER

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It is shown that continuous basalt fiber can be made from unconventional rock from different countries. The main technological parameters of the continuous-fiber production from basic rocks with SiO_2 content from 45 to 50% are determined. The main physical-chemical characteristics of continuous basalt fiber are studied.

Key words: rocks, deposits, SiO_2 content, continuous basalt fiber, physical-chemical properties.

Owing to their unique properties materials based on basalt fiber have found wide applications in diverse industries:

– automobile industry (filters, liners, brake pads, exhaust pipe, sound insulation);

– petrochemical industry (filters for process gas purification, sound insulation in commercial mufflers, filters for removing petroleum products from drain waters, process pipelines);

– construction industry (nonflammable, chemically stable structures and strong structural pieces);

– aviation industry (fireproof insulation for engines, onboard parts of airplanes);

– machine building industry (heat insulation, structural parts);

– commercial and civilian construction (materials for building earthquake resistant buildings);

– space technology and rocket engineering (wiring insulation, sealing elements, molded parts and others);

– food industry (pipelines for conveying liquid food products).

Today, the major manufacturers of continuous basalt fiber (CBF) use raw material from deposits in western Ukraine or Georgia. These are mainly andesitic basalts with SiO_2 content > 50%. The melts of these rocks at production temperatures have high viscosity, which predetermines their use in the production of continuous fiber. The characteristics of the basalt fiber obtained are close to those of a high-modulus glass fiber. However, in terms of chemical stability, strength and heat-resistance these fibers greatly surpass glass fibers. All this makes it possible to characterize andesitic basalts from deposits in western Ukraine as high-quality raw material for the production of basalt fiber.

But the high material costs of transporting raw material from its deposits in the ground to the processing site are impediments to the wide development of basalt-fiber production directly at its point of use. Sometimes the raw material is delivered from western Ukraine over thousands of kilometers into Russia, China and other countries.

At the same time the main rocks with SiO_2 content from 40 to 50% are quite widespread on the Earth. Deposits of basaltic rocks occur in many regions throughout the world, and a wide network of quarries where such rocks are mined exists at the locations of such deposits. The mined rocks are used in construction, while their suitability for obtaining basalt fibers remains practically unstudied.

In the course of scientific research, samples of basalt raw material in operating mines in different countries were studied and the characteristics found were compared with raw material from Ukrainian deposits. The average chemical composition of the rocks studied is presented in Table 1.

As one can see from Table 1, the chemical composition of the rocks from different deposits is close to that of basaltic rock from the Podgornyanskoe deposit; this is explained by the common mechanism of the formation of basaltic rock in the Earth's crust.

Important technological parameters of basalt-fiber production are the initial and final melting temperatures of the raw material. These quantities indirectly characterize the energy expended on obtaining melt.

The initial melting temperature $t_{in.melt}$ is the temperature of the primary rock melt and sticking of the melt to the metal

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TABLE 1. Average Chemical Composition of Rocks from Different Deposits

Country, rock	Content, wt.%								
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
Tadzhikistan, andesitic porphyrite	49.05	2.83	12.49	3.98	10.25	5.37	8.54	3.34	0.65
Uzbekistan, basalt	48.20	0.60	11.80	4.12	6.20	9.15	13.30	1.45	2.25
Syria, tefritic basalt	45.88	1.91	15.48	12.50	5.00	9.50	4.50	47.88	
Georgia, basalt	49.80	2.75	15.10	8.48	6.38	5.13	7.34	1.40	0.75
China, toleitic basalt	48.03	2.85	12.59	3.88	8.15	5.47	10.50	2.32	2.68
Ukraine, andesitic basalt from the Podgornyanskoe deposit	52.80	1.17	18.14	5.28	5.10	3.72	8.44	2.24	1.37

TABLE 2. Initial and Final Melting Temperatures of the Experimental Samples

Country, rock	Temperature, °C	
	$t_{in.melt}$	$t_{f.melt}$
Tadzhikistan, andesitic porphyrite	1150	1380
Uzbekistan, basalt	1140	1340
Syria, tefritic basalt	1110	1320
Georgia, basalt	1150	1400
China toleitic basalt	1120	1320
Ukraine, andesitic basalt from the Podgornyanskoe deposit	1165	1400

TABLE 3. Viscosity of the Experimental Samples versus the Temperature of the and the Temperature of the Upper Limit of Crystallization $t_{u.l.c}$, °C

Country, rock	Viscosity, dPa · sec, at t, °C					$t_{u.l.c}$, °C
	1450	1400	1350	1300	1250	
Tadzhikistan, andesitic porphyrite	142	270	470	880	1780	1250
Uzbekistan, basalt	36	62	102	185	360	1260
Syria, tefritic basalt	26	50	78	135	268	1230
Georgia, basalt	110	170	220	720	1600	1250
China, toleitic basalt	22	47	68	190	520	1220
Ukraine, andesitic basalt from the Podgornyanskoe deposit	155	220	490	945	1800	1240

surface of a plate, while the final melting temperature $t_{f.melt}$ is the temperature of complete spreading of the melted rock, and the surface of the spread melt must be shiny, smooth and must not have any visible crystalline and gaseous inclusions.

The results of the studies performed on rock samples from the deposits indicated above are presented in Table 2.

The narrowest melting interval characterizes basalt from China. Correspondingly, the time for preparing melt for production and the energy consumption on melting will be lower. The interval is 10° larger for tefritic basalt from Syria, and all other rocks have approximately the same intervals. The final melting temperature of all rocks is less than 1400°C, while for the rock conventionally used for CBF production with SiO_2 content > 50% the final melting temperature $t_{f.melt}$ is higher.

Another important indicator characterizing the suitability of rock for continuous-fiber production is the viscosity of the melt. This indicator affects the entire technological process, starting from melt homogenization and ending with fiber formation. The melt viscosity largely depends on the melt temperature and determines the possibility of obtaining fiber.

A standard viscosimeter, which was calibrated on a standard glass sample, was used to study the melt viscosity. The relative measurement error was 6% with confidence probability $P = 0.94$. For the measurements, the melt sample was kept in the experimental temperature interval for 0.5 h. The temperature of the upper limit of crystallization of the melt $t_{u.l.c}$ was also determined in parallel with the viscosity measurements. This indicator characterizes the upper limit of the crystallization of the melt with cooling and is determined by the quench method. The measurements of these parameters are presented in Table 3.

These investigations showed that andesitic prophyrite forms a melt with high viscosity and a relatively low upper limit of crystallization ($t_{u.l.c} = 1250$°C). According to previously determined criteria such melts can be suitable (in the single-component form) only for the production of continuous basalt fibers and also rough fibers obtained by mechanical pulling. In addition, a large number of crystallites were found in samples of these melts, which makes it difficult to pull fiber from melt of this kind (Fig. 1).

Melts from tefritic basalt and toleitic basalt, which the criteria show to be suitable for obtaining both fine and rough staple fiber, have the highest viscosity. There were some difficulties with melting tefritic basalt. In connection with the presence of pores in the rock a part of the raw material is not loaded into the melt, which will have a negative effect on fiber quality and, possibly, will promote the formation of blockages in the pouring apparatus.

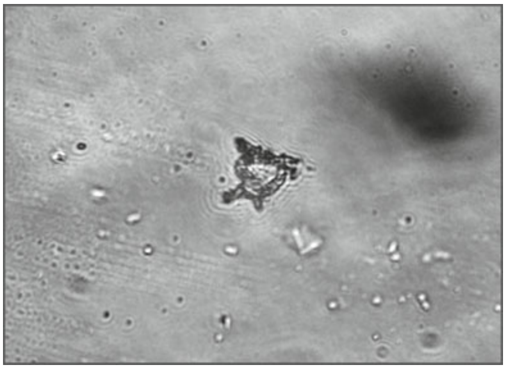

Fig. 1. Crystallites in melt of andesitic prophyrite from Tadzhikistan; ×1500.

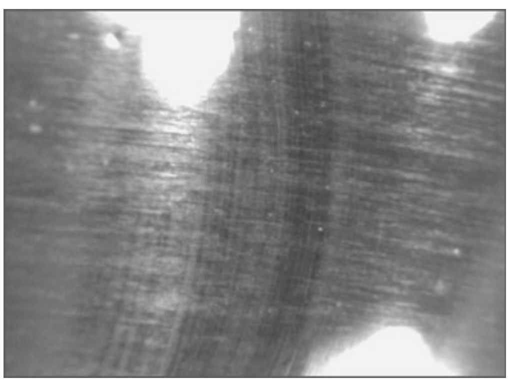

Fig. 2. Glass from toleitic basalt; ×200.

Fig. 3. Glass from Uzbekistan basalt; ×200.

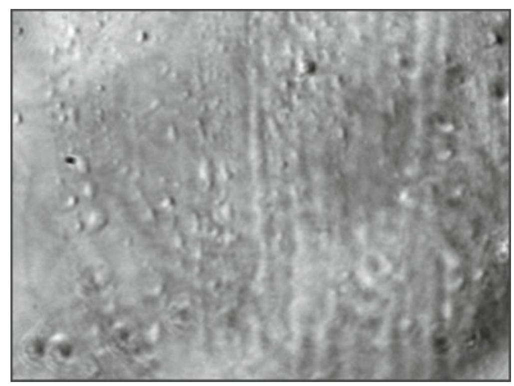

Fig. 4. Microstructure of glass from Georgian basalt; ×1500.

The capability of melts to form fibers was studied under laboratory conditions using a 14-die feeder with 2.2 mm in diameter dies. The continuous fiber was pulled at a constant rate equal to 1080 m/min.

One of the most important criteria for evaluating the suitability of rock for obtaining fibers is the temperature interval of production $t_{i.p}$. This interval was taken to be the upper and lower temperature limits within which a fiber is produced a single opening without breaking in 30 min. The determination of the temperature interval for continuous-fiber production consists in measuring the maximum and minimum fiber production temperatures with the filament pulled mechanically onto a rotating spool. Fiber production is considered to be stable if the following are absent in the process: breakage, melt pulsation at the outlet from a die and nonuniformity of the indicators of the temperature and level of the melt in the furnace feeder over the diameter. The results of these studies on determining the temperature interval of fiber production and the fiber diameter are presented in Table 4.

For practically all rocks no foaming was observed during melting in the furnace and the surface of the melt was clean.

Examinations under a microscope showed that the microstructure of the main bulk of the glass made from toleitic basalt from the Chinese deposit is uniform, showing no inclusions (Fig. 2), just as is glass from Syrian tefritic basalt.

Microcrystallites no larger than 2 μm are encountered in basalt from Uzbekistan. This explains the strong crystallization capacity of the melt (Fig. 3).

The microstructure of the bulk of the glass from Georgian basalt is uniform (Fig. 4).

Depending on the operating conditions of fiber parts, fibers must possess definite physical-chemical properties, the most important of which are constant diameter along the

TABLE 4. Temperature Interval of Production and Diameter of Continuous Fibers

Country, rock	$t_{i.p}$, °C	Fiber diameter, μm
Tadzhikistan, andesitic porphyrite	1320 – 1420	9.0 – 12.0
Uzbekistan, basalt	1310 – 1390	10.0 – 14.0
Syria, tefritic basalt	1300 – 1400	9.0 – 12.0
Georgia, basalt	1360 – 1450	9.0 – 14.0
China, toleitic basalt	1275 – 1350	8.0 – 11.0
Ukraine, andesitic basalt from the Podgornyanskoe deposit	1370 – 1450	8.0 – 13.0

TABLE 5. Physical-Mechanical and Chemical Properties of 12 μm in Diameter Fibers obtained in the Laboratory

Country, rock	σ_{ten}, MPa	Chemical resistance, %		
		H_2O	2N NaOH	2N HCl
Tadzhikistan, andesitic porphyrite	2200	99.4	72	86
Uzbekistan, basalt	2000	99.1	76	84
Syria, tefritic basalt	2600	99.2	68	76
Georgia, basalt	2000	99.0	80	83
China, toleitic basalt	1800	99.4	85	83
Ukraine, andesitic basalt from the Podgornyanskoe deposit	2000	99.5	79.2	58.9

length of a fiber, strength under stretching and chemical resistance to different aggressive media.

The diameter of an elementary continuous fiber was measured under a microscope with magnification ×750. Tests of the tensile strength were performed for working sample length 15 mm.

The measurements of the diameter and ultimate tensile strength σ_{ten} are presented in Table 5.

These studies showed that the fibers obtained possess high strength characteristics and are no worse than fibers made of andesitic basalt from the Podgornyanskoe deposit, which were obtained under the same conditions. And the fibers made from andesitic basalt from Tadzhikistan and tefritic basalt from Syrian are stronger.

The chemical resistance of the fibers was determined by the standard method of boiling for three hours in an aggressive medium. The indicators of chemical stability are presented in Table 5.

As one can see from Table 5, fiber made from practically all basalts possesses quite high resistance to acids and bases, which corresponds to industrial samples of basalt fiber from Ukraine.

CONCLUSIONS

The fibers obtained from different rocks have unique properties. Some characteristics of the processes used to obtain fiber are close. For example, the temperature difference between the start of melting is no more than 40°C. The temperature difference between the end of melting is greater than 80°C; this is explained by the presence of more refractory minerals in some rocks.

The viscosity of the melts differs considerably, which correspondingly affects the fiber production parameters, specifically, the production interval. The fiber production interval of low-viscosity rocks is shifted to lower temperatures. This is especially clearly expressed for toleitic basalt from China — the production interval is 1275 – 1350°C.

The diameter of fiber obtained from different rocks is approximately the same, but the equipment implementation and the technological parameters strongly affect its change.

The strength of all fibers is practically the same. Fiber based on tefritic basalt from Syria is an exception: it is 30% higher on average. This can be explained by the large amount of volcanic glass in the rock (> 40%), which gives fewer crystallites in the glass obtained from melt.

The fibers obtained from the deposits studied all have the same chemical resistance. It is evident that the acid resistance of the fibers obtained is more than 17% higher than that of fibers produced using andesitic basalt from the Podgornyanskoe deposit.

Practically all basalt rocks from the deposits studied can be used to obtain mineral fibers, but unequivocal conclusions can be drawn only after detailed studies have been made and the technological parameters have been finalized.